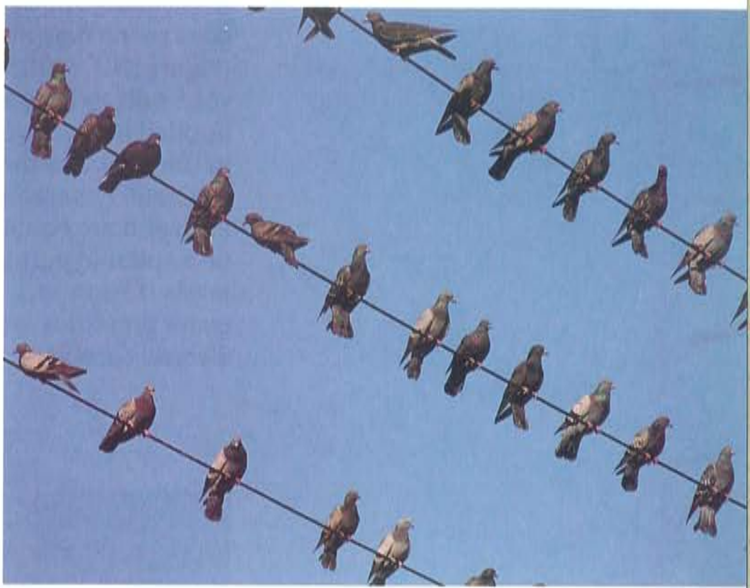
34 Electric Current

Chapter 34 uses the water flow analogy for electric current. This material in this chapter is extended in Chapter 35.



Negligible potential difference across the birds' feet.

The previous chapter discussed the concept of electric potential, or voltage. This chapter will show that voltage is an "electric pressure" that can produce a flow of charge, or *current,* within a conductor. The flow is restrained by the *resistance* it encounters. When the flow takes place along one direction, it is called *direct current* (dc); when it flows to and fro, it is called *alternating current* (ac). The rate at which energy is transferred by electric current is *power.* You'll note here that there are many terms to be sorted out. This is easier (and more meaningful) to do when you have some understanding of the ideas these terms represent. In turn, the ideas are better understood if you know how they relate to one another. Let's begin with the flow of electric charge.

Stress that the meaning of these new terms is important to understanding this chapter. Each term is defined in more depth at the place in the chapter where it is first discussed.

34.1 Flow of Charge

Important Term

potential difference

Recall in your study of heat and temperature that heat flows through a conductor when a difference in temperature exists across its ends. Heat flows from the end of higher temperature to the end of lower temperature. When both ends reach the same temperature, the flow of heat ceases.

In a similar way, when the ends of an electric conductor are at different electric potentials, charge flows from one end to the other. Charge flows when there is a **potential difference,** or difference in potential (voltage), across the ends of a conductor. The flow of charge will continue until both ends reach a common potential. When there is no potential difference, there is no longer a flow of charge through the conductor.

As an example, if one end of a wire were connected to the ground and the other end placed in contact with the sphere of a Van de Graaff generator that is charged to a high potential, a surge of charge

Videotape: Show "Electric Current" from the series *Conceptual Physics Alive!*

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Demo: Electric Potential

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Chapter 2

would flow through the wire. The flow would be brief, however, for the sphere of the generator would quickly reach a common potential with the ground.

To attain a sustained flow of charge in a conductor, some arrangement must be provided to maintain a difference in potential while charge flows from one end to the other. The situation is analogous to the flow of water from a higher reservoir to a lower one (Figure 34.1, left). Water will flow in a pipe that connects the reservoirs only as long as a difference in water level exists. (This is implied in the saying "Water seeks its own level.") The flow of water in the pipe, like the flow of charge in the wire that connects the Van de Graaff generator to the ground, will cease when the pressures at each end are equal. In order that the flow be sustained, there must be a suitable pump of some sort to maintain a difference in water levels (Figure 34.1, right). Then there will be a continual difference in water pressures and a continual flow of water. The same is true of electric current.

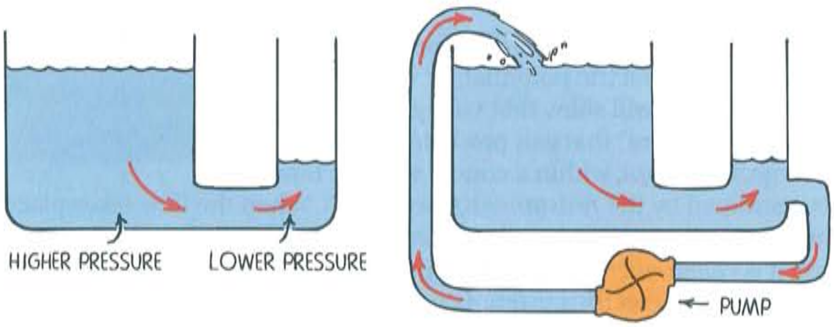


Figure 34.1 ▲
(Left) Water flows from the higher-pressure end of the pipe to the lower-pressure end. The flow will cease when the difference in pressure ceases. (Right) Water continues to flow because a difference in reservoir level is maintained with the pump.

rtant Terms

ere
ric current

roplating is an example of of ions in a fluid.

ampere is named in honor e French physicist, André-e Ampère (1775–1836).

fact that a current-carrying has no net charge can be ined by having the class ine a tube completely ed with Ping-Pong balls. If push in one more Ping- ball, another one will pop nstantly on the other side.

34.2 Electric Current

Electric current is simply the flow of electric charge. In solid conductors the electrons carry the charge through the circuit because they are free to move throughout the atomic network. These electrons are called *conduction electrons*. Protons, on the other hand, are bound inside atomic nuclei that are more or less locked in fixed positions. In fluids, such as the electrolyte in a car battery, positive and negative ions as well as electrons may compose the flow of electric charge.

Electric current is measured in **amperes,** for which the SI unit is symbol A.* An ampere is the flow of 1 coulomb of charge per second. (Recall that 1 coulomb, the standard unit of charge, is the electric charge of 6.25 billion billion electrons.) In a wire that carries a current of 5 amperes, for example, 5 coulombs of charge pass any cross section in the wire each second. So that's a lot of electrons! In a wire that carries 10 amperes, twice as many electrons pass any cross section each second.

Note that a current-carrying wire does not have a *net* electric charge. While the current is flowing, negative electrons swarm through the atomic network that is composed of positively charged atomic nuclei. Under ordinary conditions, the number of electrons in the wire is equal to the number of positive protons in the atomic nuclei. When electrons flow in a wire, the number entering one end is the same as the number leaving the other. The net charge of the wire is normally zero at every moment.

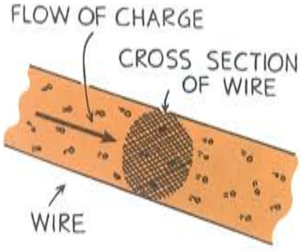


Figure 34.2 ▲
When the rate of flow of charge past any cross section is 1 coulomb (6.25 billion billion electrons) per second, the current is 1 ampere.

34.3 Voltage Sources

Charges do not flow unless there is a potential difference. A sustained current requires a suitable "electric pump" to provide a sustained potential difference. Something that provides a potential difference is known as a **voltage source.** If you charge a metal sphere positively, and another negatively, you can develop a large voltage between them. This voltage source is not a good electric pump because when the spheres are connected by a conductor, the potentials equalize in a single brief surge of moving charges. It is not practical. Dry cells, wet cells, and generators, however, are capable of maintaining a steady flow. (A battery is just two or more cells connected together.)

Dry cells, wet cells, and generators supply energy that allows charges to move. In dry cells and wet cells, energy released in a chemical reaction occurring inside the cell is converted to electric energy.** Generators—such as the alternators in automobiles—convert mechanical energy to electric energy, as discussed in Chapter 37. The electric potential energy produced by whatever means is available at the terminals of the cell or generator. The potential energy per coulomb of charge available to electrons moving between terminals is the voltage (sometimes called the *electromotive force,* or *emf*). The voltage provides the "electric pressure" to move electrons between the terminals in a circuit.

Important Term

voltage source

Point out that voltage obtained from dry cells or wet cells is no different from that obtained from a dc generator. Voltage is voltage, regardless of source.

* The SI symbol for ampere is A. However, an older symbol still in common usage is amp. People often speak of a current of, say, "5 amps."

** A description of the chemical reactions inside dry cells and wet cells can be found in almost any chemistry textbook.

gure 34.3 ▲
ch coulomb of charge that is
ade to flow in a circuit that
nnects the ends of this 1.5-volt
shlight cell is energized with
5 joules.

Power utilities use large electric generators to provide the 120 volts delivered to home outlets. The alternating potential difference between the two holes in the outlet averages 120 volts. When the prongs of a plug are inserted into the outlet, an average electric "pressure" of 120 volts is placed across the circuit connected to the prongs. This means that 120 joules of energy is supplied to each coulomb of charge that is made to flow in the circuit.

There is often some confusion between charge flowing *through* a circuit and voltage being impressed *across* a circuit. To distinguish between these ideas, consider a long pipe filled with water. Water will flow *through* the pipe if there is a difference in pressure *across* or between its ends. Water flows from the high-pressure end to the low-pressure end. Only the water flows, not the pressure. Similarly, you say that charges flow *through* a circuit because of an applied voltage *across* the circuit.* You don't say that voltage flows through a circuit. Voltage doesn't go anywhere, for it is the charges that move. Voltage causes current.

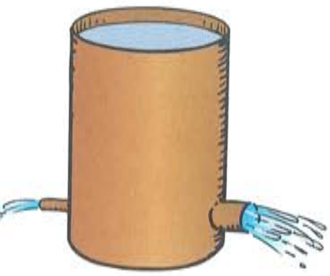
34.4 Electric Resistance

portant Terms

ctric resistance
m

The amount of current that flows in a circuit depends on the voltage provided by the voltage source. The current flow also depends on the resistance that the conductor offers to the flow of charge—the **electric resistance.** This is similar to the rate of water flow in a pipe, which depends not only on the pressure difference between the ends of the pipe but on the resistance offered by the pipe itself. The resistance of a wire depends on the *conductivity* of the material used in the wire (that is, how well it conducts) and also on the thickness and length of the wire.

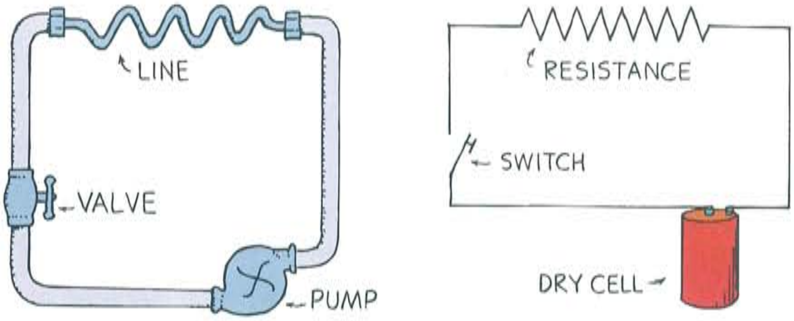
Thick wires have less resistance than thin wires. Longer wires have more resistance than short wires. In addition, electric resistance depends on temperature. The greater the jostling about of atoms within the conductor, the greater resistance the conductor offers to the flow of charge. For most conductors, increased temperature means increased resistance.** The resistance of some materials becomes zero at very low temperatures. These are the superconductors discussed briefly in Chapter 32.



ure 34.4 ▲
a given pressure, more water
ses through a large pipe than
mall one. Similarly, for a given
tage, more electric current
ses through a large-diameter
e than a small-diameter one.

* It is conceptually simpler to say that current flows through a circuit, but don't say this around somebody who is "picky" about grammar, for the expression *current flows* is redundant. More properly, charge flows, which *is* current.

** Carbon is an interesting exception. At high temperatures, electrons are shaken from the carbon atom, which increases electric current. Carbon's resistance decreases with increasing temperature. This behavior, along with its high melting temperature, accounts for the use of carbon in arc lamps.



In Fig. 34.5, note that opening the switch is equivalent to inserting an infinite resistance.

Figure 34.5 ▲
Analogy between a simple hydraulic circuit and an electric circuit.

Electric resistance is measured in units called **ohms,*** after Georg Simon Ohm, a German physicist who tested different wires in circuits to see what effect the resistance of the wire had on the current.

34.5 Ohm's Law

Important Term

Ohm's law

Ohm discovered that the current in a circuit is directly proportional to the voltage impressed across the circuit, and is inversely proportional to the resistance of the circuit. In short,

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

This relationship between voltage, current, and resistance is called **Ohm's law.****

The relationship between the units of measurement for these three quantities is

$$1 \text{ ampere} = 1 \frac{\text{volt}}{\text{ohm}}$$

So for a given circuit of constant resistance, current and voltage are proportional. This means that you'll get twice the current for twice the voltage. The greater the voltage, the greater the current. But if the resistance is doubled for a circuit, the current will be half what it would be otherwise. The greater the resistance, the less the current. Ohm's law makes good sense.

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Ohm's Law

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* The Greek letter capital Ω (omega) is usually used as a symbol for ohm.

** Many texts use *V* for voltage, *I* for current, and *R* for resistance, and express Ohm's law as $V = IR$. It then follows that $I = V/R$, or $R = V/I$, so if any two variables are known, the third can be found.

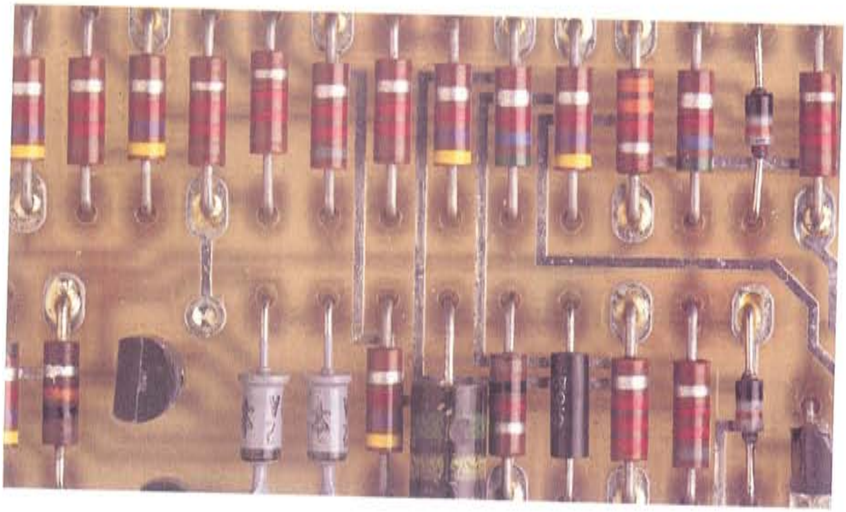

Figure 34.6 ▲
Resistors. The stripes are color coded to indicate the resistance in ohms.

IK TO ELECTROCHEMISTRY

Electrolysis

lectrochemistry is about lectric energy and chemi-al change. Molecules in liquid can be broken part and separated by e action of electric cur-nt. This is *electrolysis.* common example is assing an electric current rough water, separating ater into its hydrogen d oxygen components. is common process is so at work when a car ttery is recharged. ectrolysis is also used produce metals from es. Aluminum is a miliar metal produced electrolysis. Aluminum common today, but fore the advent of its oduction by electrolysis 1886, aluminum was ch more expensive n silver and gold!

Using specific values, a potential difference of 1 volt impressed across a circuit that has a resistance of 1 ohm will produce a current of 1 ampere. If a voltage of 12 volts is impressed across the same circuit, the current will be 12 amperes.

The resistance of a typical lamp cord is much less than 1 ohm, while a typical lightbulb has a resistance of about 100 ohms. An iron or electric toaster has a resistance of 15 to 20 ohms. The low resistance permits a large current, which produces considerable heat. Inside electric devices such as radio and television receivers, the current is regulated by circuit elements called *resistors,* whose resistance may range from a few ohms to millions of ohms.

Questions

1. What is the resistance of an electric frying pan that draws 12 amperes of current when connected to a 120-volt circuit?
2. How much current is drawn by a lamp that has a resistance of 100 ohms when a voltage of 50 volts is impressed across it?

Answers

1. The resistance is 10 ohms.

$$\text{resistance} = \frac{\text{voltage}}{\text{current}} = \frac{120 \text{ volts}}{12 \text{ amperes}} = 10 \text{ ohms}$$

An electric device is said to *draw* current when voltage is impressed across it, just as water is said to be drawn from a well or a faucet. In this sense, to draw is not to attract, but to *obtain.*

2. The current is 0.5 ampere.

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} = \frac{50 \text{ volts}}{100 \text{ ohms}} = 0.5 \text{ ampere}$$

34.6 Ohm's Law and Electric Shock

What causes electric shock in the human body—current or voltage? The damaging effects of shock are the result of current passing through the body. From Ohm's law, we can see that this current depends on the voltage applied, and also on the electric resistance of the human body.

The resistance of your body depends on its condition and ranges from about 100 ohms if you're soaked with salt water to about 500 000 ohms if your skin is very dry. If you touched the two electrodes of a battery with dry fingers, the resistance your body would normally offer to the flow of charge would be about 100 000 ohms. You usually would not feel 12 volts, and 24 volts would just barely tingle. If your skin were moist, on the other hand, 24 volts could be

Electricians usually work "with one hand in their pocket"; that is to say, they use only one hand when there is any danger of a "hot wire." If they use two hands and there is a hot wire, the current may go from one hand to another across the chest and paralyze the heart.

When electricians need to move live wires with their hands, they first touch them with the backs of their hands, so that any unexpected shocks will not cause a muscular contraction that will keep their hands gripping the wire.

Table 34.1
Effect of Various Electric Currents on the Body

Current in amperes	Effect
0.001	Can be felt
0.005	Painful
0.010	Involuntary muscle contractions (spasms)
0.015	Loss of muscle control
0.070	If through the heart, serious disruption; probably fatal if current lasts for more than 1 second

Questions

1. If the resistance of your body were 100 000 ohms, what would be the current in your body when you touched the terminals of a 12-volt battery?
2. If your skin were very moist so that your resistance was only 1000 ohms, and you touched the terminals of a 24-volt battery, how much current would you draw?

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Caution on Handling Electrical Wires

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Chapter 3

Answers

1. The current in your body, quite harmless, would be

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} = \frac{12\text{ V}}{100\ 000\ \Omega} = 0.000\ 12\text{ A}$$

2. You would draw $\frac{24\text{ V}}{1000\ \Omega}$, or 0.024 A, a dangerous amount of current!

gure 34.7 ▲
ndling a wet hair dryer can be
sticking your fingers into a
socket.

ure 34.8 ▲
bird can stand harmlessly
one wire of high potential,
it had better not reach over
grab a neighboring wire!
not?

ure 34.9 ▲
third prong connects the
of the appliance directly to
nd. Any charge that builds
n an appliance is therefore
lucted to the ground.

quite uncomfortable. Table 34.1 describes the effects of different amounts of current on the human body.

Many people are killed each year by current from common 120-volt electric circuits. If you touch a faulty 120-volt light fixture with your hand while you are standing on the ground, there is a 120-volt "electric pressure" between your hand and the ground. The soles of your shoes normally provide a very large resistance between your feet and the ground, so the current would probably not be enough to do serious harm. But if you are standing barefoot in a wet bathtub connected through its plumbing to the ground, the resistance between you and the ground is very small. Your overall resistance is lowered so much that the 120-volt potential difference may produce a harmful current through your body.

Drops of water that collect around the on-off switches of devices such as a hair dryer can conduct current to the user. Although distilled water is a good insulator, the ions in ordinary water greatly reduce the electric resistance. These ions are contributed by dissolved materials, especially salts. There is usually a layer of salt left from perspiration on your skin, which when wet lowers your skin resistance to a few hundred ohms or less. Handling electric devices while taking a bath is extremely dangerous.

You have seen birds perched on high-voltage wires. Every part of their bodies is at the same high potential as the wire, and they feel no ill effects. For the bird to receive a shock, there must be a *difference* in electric potential between one part of its body and another part. Most of the current will then pass along the path of least electric resistance connecting these two points.

Suppose you fell from a bridge and managed to grab onto a high-voltage power line, halting your fall. So long as you touch nothing else of different potential, you will receive no shock at all. Even if the wire is thousands of volts above ground potential and even if you hang by it with two hands, no charge will flow from one hand to the other. This is because there is no appreciable difference in electric potential between your hands. If, however, you reach over with one hand and grab onto a wire of different potential, ZAP!!

Mild shocks occur when the surfaces of electric appliances are at an electric potential different from that of the surfaces of other nearby devices. If you touch surfaces of different potentials, you become a pathway for current. Sometimes the effect is more than mild. To prevent this problem, the outsides of electric appliances are connected to a ground wire, which is connected to the round third prong of a three-wire electric plug (Figure 34.9). All ground wires in all plugs are connected together through the wiring system of the house. The two flat prongs are for the current-carrying double wire. If the live wire accidentally comes in contact with the metal surface of an appliance, the current will be directed to ground rather than shocking you if you handle it.

One effect of electric shock is to overheat tissues in the body or to disrupt normal nerve functions. It can upset the nerve center that controls breathing. In rescuing victims, the first thing to do is clear them from the electric supply with a wooden stick or some other nonconductor so that you don't get electrocuted yourself. Then apply artificial respiration.

■ Question

What causes electric shock—current or voltage?

Important Terms

alternating current
direct current

34.7 Direct Current and Alternating Current

Electric current may be *dc* or *ac*. By *dc*, we mean **direct current,** which refers to a flow of charge that *always flows in one direction.* A battery produces direct current in a circuit because the terminals of the battery always have the same sign of charge. Electrons always move through the circuit in the same direction, from the repelling negative terminal and toward the attracting positive terminal. Even if the current moves in unsteady pulses, so long as it moves in one direction only, it is dc.

Alternating current (ac) acts as the name implies. Electrons in the circuit move first in one direction and then in the opposite direction, alternating back and forth about relatively fixed positions. This is accomplished by alternating the polarity of voltage at the generator or other voltage source. Nearly all commercial ac circuits in North America involve voltages and currents that alternate back and forth at a frequency of 60 cycles per second. This is 60-hertz current. In some places, 25-hertz, 30-hertz, or 50-hertz current is used.

Voltage of ac in North America is normally 120 volts.* In the early days of electricity, higher voltages burned out the filaments of electric lightbulbs. Tradition has it that 110 volts was settled on because it made bulbs of the day glow as brightly as a gas lamp. So the hundreds of power plants built in the United States prior to 1900 adopted 110 volts (or 115 or 120 volts) as their standard. By the time electricity became popular in Europe, engineers had figured out how to make lightbulbs that would not burn out so fast at higher voltages. Power transmission is more efficient at higher voltages, so Europe adopted 220 volts as their standard. The United States stayed with 110 volts (today officially 120 volts) because of the installed base of 110-volt equipment.

Although lamps in an American home operate on 110–120 volts, many electric stoves and other power-hungry appliances operate on 220–240 volts. How is this possible? Because most electric service in the United States is three-wire: one wire at 120 volts positive, one

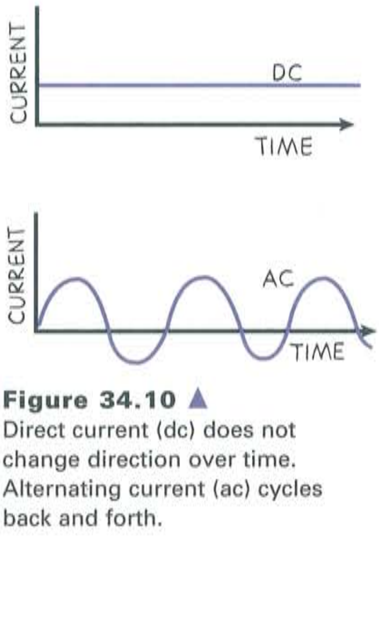

Figure 34.10 ▲
Direct current (dc) does not change direction over time. Alternating current (ac) cycles back and forth.

■ Answer

The initial *cause* is the voltage, but it is the current that does most of the damage.

* If you study electricity further you'll learn that 120 volts refers to the "root-mean-square" average of the voltage. The actual voltage in a 120-volt ac circuit varies between +170-volt and −170-volt peaks. It delivers the same power to an iron or a toaster as a 120-volt dc circuit.

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Alternating Current

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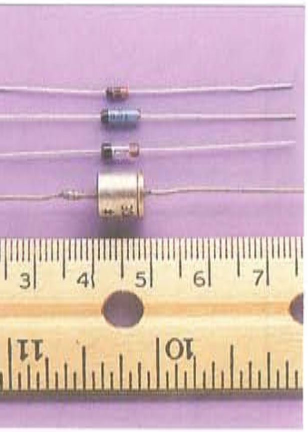
wire at zero volts (neutral), and the other wire at a negative 120 volts. This is ac, with the positive and negative alternating at 60 hertz. A wire that is positive at one instant is negative 1/120 of a second later. Most home appliances are connected between the neutral wire and either of the other two wires, producing 120 volts. When the plus-120 is connected to the minus-120,* a 240-volt jolt is produced—just right for electric stoves, air conditioners, and clothes dryers.

The popularity of ac arises from the fact that electric energy in the form of ac can be transmitted great distances with easy voltage step-ups that result in lower heat losses in the wires. Why this is so will be discussed in Chapter 37.

The primary use of electric current, whether dc or ac, is to transfer energy quietly, flexibly, and conveniently from one place to another.



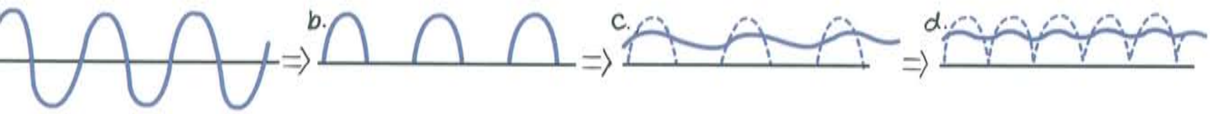
re 34.11 ▲

es.

34.8 Converting AC to DC

The current in your home is ac. The current in a battery-operated device, such as a pocket calculator, is dc. With an ac-dc converter you can operate such a device on ac instead of batteries. In addition to a transformer to lower the voltage (Chapter 37), the converter uses a **diode,** a tiny electronic device that acts as a one-way valve to allow electron flow in only one direction. Since alternating current vibrates in two directions, only half of each cycle will pass through a diode. The output is a rough dc, off half the time. To maintain continuous current while smoothing the bumps, a capacitor is used (Figure 34.12).

Recall from the previous chapter that a capacitor acts as a storage reservoir for charge. Just as it takes time to raise or lower the water level in a reservoir, it takes time to add or remove electrons from the plates of a capacitor. A capacitor therefore produces a retarding effect on changes in current flow. It smooths the pulsed output.



rtant Term

Figure 34.12 ▲
(a) When input to a diode is ac, (b) output is pulsating dc. (c) Charging and discharging of a capacitor provides continuous and smoother current. (d) In practice, a pair of diodes are used so there are no gaps in current output. The effect is to reverse the polarity of alternate half-cycles instead of eliminating them.

* The "plus" and "minus" are arbitrary, because they alternate. The important thing is that they are opposite.

34.9 The Speed of Electrons in a Circuit

When you flip on the light switch on your wall and the circuit is completed, the lightbulb appears to glow immediately. When you make a telephone call, the electric signal carrying your voice travels through the connecting wires at seemingly infinite speed. This signal is transmitted through the conductors at nearly the speed of light. It is *not* the electrons that move at this speed but the signal.

At room temperature, the electrons inside a metal wire have an average speed of a few million kilometers per hour due to their thermal motion. This does not produce a current because the motion is random. There is no net flow in any one direction. But when a battery or generator is connected, an electric field is established inside the wire. It is a pulsating electric field that can travel through a circuit at nearly the speed of light. The electrons continue their random motions in all directions while simultaneously being nudged along the wire by the electric field.

The conducting wire acts as a guide or "pipe" for electric field lines (Figure 34.13). In the space outside the wire, the electric field has a pattern determined by the location of electric charges, including charges in the wire. Inside the wire, the electric field is directed along the wire. If the voltage source is dc, like the battery shown in Figure 34.13, the electric field lines are maintained in one direction in the conductor.

Stress that only the electric field, not the electrons, travels at the speed of light. Many students get this wrong on tests, indicating they have this wrong conceptually.

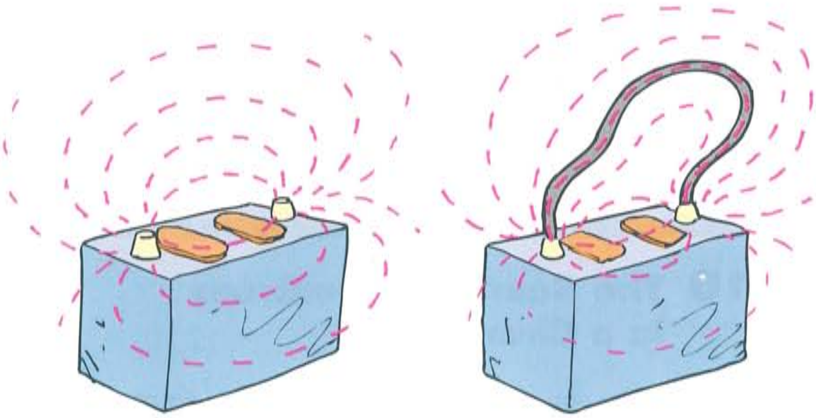


Figure 34.13 ▲
The electric field lines between the terminals of a battery are directed through a conductor, which joins the terminals.

Conduction electrons are accelerated by the field in a direction parallel to the field lines. Before they gain appreciable speed, they "bump into" the anchored metallic ions in their paths and transfer some of their kinetic energy to them. This is why current-carrying wires become hot. These collisions interrupt the motion of the electrons so that their actual *drift speed,* or *net speed* through the wire

due to the field, is extremely low. In a typical dc circuit, in the electric system of an automobile for example, electrons have a net average drift speed of about 0.01 cm/s. At this rate, it would take about three hours for an electron to travel through 1 meter of wire.

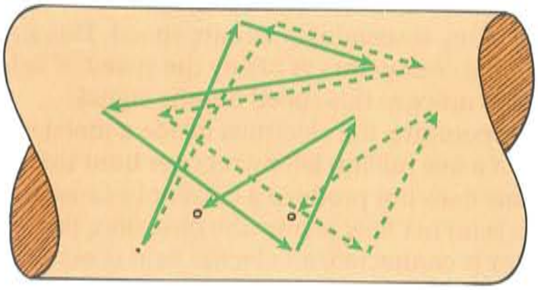
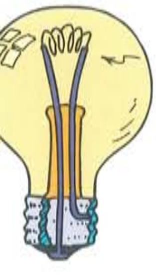


Figure 34.14 ▲
The solid lines depict a possible random path of an electron bouncing off atoms in a conductor. Instantaneous speeds are about 1/200 the speed of light. The dashed lines show an exaggerated view of how this path may be altered when an electric field is applied. The electron drifts toward the right with an average speed much less than a snail's pace.

In an ac circuit, the conduction electrons don't make any net progress in any direction. In a single cycle they drift a tiny fraction of a centimeter in one direction, then the same tiny distance in the opposite direction. Hence they oscillate rhythmically to and fro about relatively fixed positions. When you talk to your friend on the telephone, it is the *pattern* of oscillating motion that is carried across town at nearly the speed of light. The electrons already in the wires vibrate to the rhythm of the traveling pattern.



ure 34.15 ▲
conduction electrons that e to and fro in the filament e lamp do not come from voltage source. They are in ilament to begin with. The ge source simply provides n with surges of energy.

34.10 The Source of Electrons in a Circuit

In a hardware store you can buy a water hose that is empty of water. But you can't buy a piece of wire, an "electron pipe," that is empty of electrons. The source of electrons in a circuit is the conducting circuit material itself. Some people think that the electric outlets in the walls of their homes are a source of electrons. They think that electrons flow from the power utility through the power lines and into the wall outlets of their homes. This is not true. The outlets in homes are ac. Electrons do not travel appreciable distances through a wire in an ac circuit. Instead, they vibrate to and fro about relatively fixed positions.

When you plug a lamp into an ac outlet, *energy* flows from the outlet into the lamp, not electrons. Energy is carried by the electric field and causes a vibratory motion of the electrons that already exist

in the lamp filament. If 120 volts ac are impressed on a lamp, then an average of 120 joules of energy are dissipated by each coulomb of charge that is made to vibrate. Most of this electric energy appears as heat, while some of it takes the form of light. Power utilities do not sell electrons. They sell *energy.* You supply the electrons.

Thus, when you are jolted by an ac electric shock, the electrons making up the current in your body originate in your body. Electrons do not come out of the wire and through your body and into the ground; energy does. The energy simply causes free electrons in your body to vibrate in unison. Small vibrations tingle; large vibrations can be fatal.

Stress that only energy, not electrons, is supplied via the outlet. It is a common misconception.

34.11 Electric Power

Important Term

electric power

Unless it is in a superconductor, a charge moving in a circuit expends energy. This may result in heating the circuit or in turning a motor. The rate at which electric energy is converted into another form such as mechanical energy, heat, or light is called **electric power.** Electric power is equal to the product of current and voltage.*

$$\text{electric power} = \text{current} \times \text{voltage}$$

If the voltage is expressed in volts and the current in amperes, then the power is expressed in watts. So in units form,

$$1 \text{ watt} = (1 \text{ ampere}) \times (1 \text{ volt})$$

If a lamp rated at 120 watts operates on a 120-volt line, you can see that it will draw a current of 1 ampere, since 120 watts = (1 ampere) × (120 volts). A 60-watt lamp draws 0.5 ampere on a 120-volt line. This relationship becomes a practical matter when you wish to know the cost of electric energy, which varies from 1 cent to 10 cents per kilowatt-hour depending on locality.

A *kilowatt* is 1000 watts, and a *kilowatt-hour* represents the amount of energy consumed in 1 hour at the rate of 1 kilowatt.**

* Note that this follows from the definitions of current and voltage:

$$\text{current} \times \text{voltage} = \frac{\cancel{\text{charge}}}{\text{time}} \times \frac{\text{energy}}{\cancel{\text{charge}}} = \frac{\text{energy}}{\text{time}} = \text{power}$$

** Since power = energy/time, simple rearrangement gives energy = power × time; hence, energy can be expressed in units of kilowatt-hours.

Physicists measure energy in *joules,* but utility companies customarily sell energy in units of *kilowatt-hours* (kW•h), where 1kW•h = 3.6×10^6 J. This duplication of units added to an already long list of units unfortunately makes the study of physics more difficult. It will be enough for you to become familiar with, and be able to distinguish between, the units *coulombs, volts, ohms, amperes, watts, kilowatts,* and *kilowatt-hours* here. Mastering them requires laboratory work and the help of more advanced textbooks. An understanding of electricity takes considerable time and effort, so be patient with yourself if you find this material difficult.

e current through the bulb Fig. 34.16 will be 60 W/120 V).5 A.

mmed headlights: An auto ttery has internal resistance. nen current flows in the bat- y, there is a voltage drop oss this resistance, and me heating occurs. This kes the voltage across the minals drop as the current reases. When the car's rter is activated, consider- e current flows through the tery, lowering the voltage put of the battery. This is dent in the dimmed head- ts.

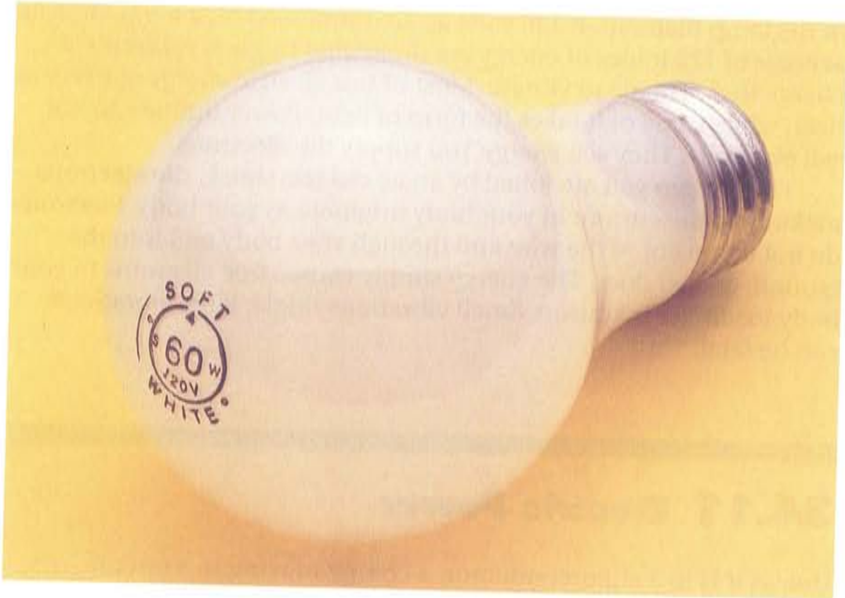


Figure 34.16 ▲
The power and voltage on the lightbulb read "60 W 120 V." How much current in amperes will flow through the bulb?

Therefore, in a locality where electric energy costs 5 cents per kilowatt-hour, a 100-watt electric lightbulb can be run for 10 hours at a cost of 5 cents, or a half-cent for each hour. A toaster or iron, which draws more current and therefore more power, costs several times as much to operate for the same time.

Questions

1. How much power is used by a calculator that operates on 8 volts and 0.1 ampere? If it is used for one hour, how much energy does it use?
2. Will a 1200-watt hair dryer operate on a 120-volt line if the current is limited to 15 amperes by a safety fuse? Can two hair dryers operate on this line?

Answers

1. Power = current × voltage = (0.1 A) × (8 V) = 0.8 W. If it is used for one hour, then energy = power × time = (0.8 W) × (1 h) = 0.8 watt-hour, or 0.0008 kilowatt-hour.
2. One 1200-watt hair dryer can be operated because the circuit can provide (15 A) × (120 V) = 1800 watts. But there is inadequate power to operate two hair dryers of combined power 2400 watts. This can be seen also from the amount of current involved. Since 1 watt = (1 ampere) × (1 volt), it follows that (1200 watts)/(120 volts) = 10 amperes; so the hair dryer will operate when connected to the circuit. But two hair dryers on the same plug will require 20 amperes and will blow the 15-amp fuse.

34 Chapter Review

For fuller explanations, see the TE notes in the front of this book.

Concept Summary

Electric current is the flow of electric charge that occurs when there is a potential difference across the ends of an electric conductor.

- The flow continues until both ends reach a common potential.
- Dry cells, wet cells, and electric generators are voltage sources that maintain a potential difference in a circuit.

The amount of current that flows in a circuit depends on the voltage and the electric resistance that the conductor offers to the flow of charge.

- An increased temperature or a longer wire increases resistance.
- A thicker wire decreases resistance.

Ohm's law states that the amount of current is directly proportional to the voltage and inversely proportional to the resistance.

- Resistors are used in many electric devices to control current.
- Electric shock is the result of an electric current passing through the body when there is a voltage difference between two parts of the body.

Direct current (dc) is electric current in which the charge flows in one direction only; electrons in an alternating current (ac) alternate their direction of flow.

- Batteries produce direct current. Power utilities produce alternating current.
- Alternating current allows low-cost, high-voltage energy transmission across great distances, with safe low-voltage use by the consumer.

Electric fields travel through circuits at nearly the speed of light, but the electrons themselves do not.

- In a dc circuit, electrons have a low drift speed within wires.
- In ac circuits, energy, not electrons, flows from the outlet; the electrons superimpose a rhythmic vibration on rapid random motion.

Electric power, the rate at which electric energy is converted into other forms of energy, is equal to the product of current and voltage.

Important Terms

alternating current (34.7)
ampere (34.2)
diode (34.8)
direct current (34.7)
electric current (34.2)
electric power (34.11)
electric resistance (34.4)
ohm (34.4)
Ohm's law (34.5)
potential difference (34.1)
voltage source (34.3)

Review Questions

Recall of key chapter ideas

1. What condition is necessary for the flow of heat? What analogous condition is necessary for the flow of charge? (34.1) Temperature difference; voltage difference
2. What is meant by the term *potential*? What is meant by *potential difference*? (34.1) PE/q; ΔPE/q between points
3. What condition is necessary for the sustained flow of water in a pipe? What analogous condition is necessary for the sustained flow of charge in a wire? (34.1) Pressure difference; potential difference
4. What is electric current? (34.2) Flow of charge
5. What is an ampere? (34.2) Flow of 1 coulomb per second
6. What is voltage? (34.3) Electric "pressure," PE/q, that produces elect current
7. How many joules per coulomb are given to charges that flow in a 120-volt circuit? (34.3) 120 J/C = 120 V

Does charge flow through a circuit or into a circuit? (34.3)
Flows through a circuit

Does voltage flow through a circuit, or is voltage established across a circuit? (34.3)
Established across, only charge flows

What is electric resistance? (34.4) That which resists flow of charge, in ohms

Is electric resistance greater in a short fat wire or a long thin wire? (34.4) Greater resistance in long thin wire

What is Ohm's law? (34.5)
Current = voltage/resistance

If the voltage impressed across a circuit is constant but the resistance doubles, what change occurs in the current? (34.5) Drops to half, in accord with Ohm's law

If the resistance of a circuit remains constant while the voltage across the circuit decreases to half its former value, what change occurs in the current? (34.5)
Half as much current

How does wetness affect the resistance of your body? (34.6) Wetness lowers skin resistance

Why is it that a bird can perch without harm on a high-voltage wire? (34.6) Negligible potential difference across body

What is the function of the third prong in a household electric plug? (34.6) Serves as a ground

Distinguish between dc and ac. Which is produced by a battery and which is usually produced by a generator? (34.7) Direct current, alternating current, battery is dc

A diode converts ac to pulsed dc. What electric device smooths the pulsed dc to a smoother dc? (34.8)
A capacitor

What are the roles of a diode and a capacitor in an ac-dc converter? (34.8) Diode converts ac to dc, capacitor smooths current

What is a typical "drift" speed of electrons that make up a current in a typical dc circuit? In a typical ac circuit? (34.9) In dc, less than 1 cm/s; in ac, zero drift speed

From where do the electrons originate that flow in a typical electric circuit? (34.10)
From conductors themselves

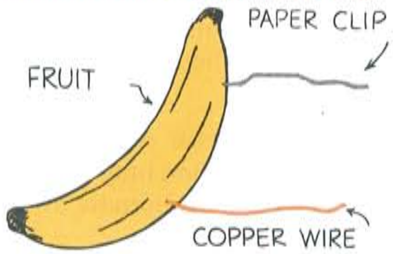
23. What is power? (34.11)
Power = energy/time, rate of doing work

24. Which of these is a unit of power and which is a unit of electric energy: a watt, a kilowatt, a kilowatt-hour? (34.11) Power: watt, kilowatt; energy: kilowatt-hour

25. How many amperes flow through a 60-watt bulb when 120 volts are impressed across it? (34.11) From $P = IV$, 60 W = $I \times$ (120 V); $I = 0.5$ A

Activity

1. Batteries are made up of electric cells, which are composed of two unlike pieces of metal separated by a conducting solution. A simple 1.5-volt cell, equivalent to a flashlight cell, can be made by placing a strip of copper and a strip of zinc in a moist vegetable or piece of fruit as shown in the figure. A lemon or banana works fine. Hold the ends of the strips close together but not touching, and place the ends on your tongue. The slight tingle you feel and the metallic taste you experience result from a slight current of electricity pushed by the cell through the metal strips when your moist tongue closes the circuit. Try this and compare the results for different metals and different fruits and vegetables. All moist objects will work to varying degrees



Plug and Chug

Math reinforcement—conceptual development through applied problem solving

1. Calculate the current where 10 coulombs of charge pass a point in 5 seconds.
Current = (10 C)/(5 s) = 2 A

2. Calculate the current of a lightning bolt that delivers a charge of 35 coulombs to the ground in a time of 1/1000 second.
Current = (35 C)/(10^{-3} s) = 35 000 A

3. Calculate the current in a toaster that has a heating element of 14 ohms when connected to a 120-V outlet. Current = V/R = (120 V)/(14 Ω) = 8.6 A

4. Calculate the current in the coiled heating element of a 240-V stove. The resistance of the element is 60 ohms at its operating temperature.
Current = V/R = (240 V)/(60 Ω) = 4 A

5. Electric socks, popular in cold weather, have a 90-ohm heating element that is powered by a 9-volt battery. How much current warms your feet?
Current = V/R = (9 V)/(90 Ω) = 0.1 A

6. How much current moves through your fingers (resistance: 1200 ohms) if you touch them to the terminals of a 6-volt battery?
Current = V/R = (6 V)/(1200 Ω) = 0.005 A

7. Calculate the resistance of the filament in a lightbulb that carries 0.4 A when 3.0 V is impressed across it. R = voltage/current = (3.0 V)/(0.4 A) = 7.5 Ω

8. Calculate the current in a 140-W electric blanket connected to a 120-V outlet. From $P = IV$, $I = P/V$ = (140 W)/(120 V) = 1.17 A

Think and Explain

Conceptual development through applied critical thinking

1. Is this label on a household product cause for concern? "Caution: This product contains tiny electrically charged particles moving at speeds in excess of 10 000 000 kilometers per hour." No concern, typical electron speed in any material

2. Do an *ampere* and a *volt* measure the same thing, or different things? What are those things, and which is a flow and which is the cause of the flow? Potential difference (volts) causes flow of charge (amps)

3. Why are thick wires rather than thin wires used to carry large currents? Thick wires less resistance, less heating

4. Why is it important that the resistance of an extension cord be small when it is used to power an electric heater? Less resistance, less waste heating of cord

5. Why will an electric drill operating on a very long extension cord not rotate as fast as one operated on a short cord? Voltage drop in cord, less V for drill

6. Will the current in a lightbulb connected to 220 V be more or less than when the same bulb is connected to 110 V? How much?
More current at higher voltage; double, if resist doesn't change

7. What is the effect on current if both the voltage and the resistance are doubled? If both are halved? No effect either way, by Ohm's law

8. Would you expect to find dc or ac in the dome lamp in an automobile? In a lamp in your home? Auto, dc by battery; home, ac by ac generator

9. In 60-Hz alternating current, how many times per second does an electron change its direction? (Don't say 60!) Changes direction 120 times per second

10. Two lightbulbs designed for 120-V use are rated at 40 W and 60 W. Which lightbulb has the greater filament resistance? Why? Less resist in 60-W bulb; more P for same V, more I

Think and Solve

Math reinforcement—variable substitution and equation solving

1. How much voltage is required to make 2 amperes flow through a resistance of 8 ohms?
$V = IR$ = (2 A)(8 Ω) = 16 V

2. A battery does 18 joules of work on 3 coulombs of charge. What voltage does it supply?
Voltage = E/q = (18 J)/(3 C) = 6 V

3. Use the relationship power = current × voltage to find out how much current is drawn by a 1200-watt hair dryer when it operates on 120 volts. Then use Ohm's law to find the resistance of the hair dryer. I = (1200 W)/(120 V) = 10 A; $R = V/I$ = 12 Ω

4. The wattage marked on a lightbulb is not an inherent property of the bulb but depends on the amount of voltage to which it is connected, usually 110 V or 120 V. Calculate the current through a 40-W bulb connected to 120 V.
$I = P/V$ = 40 W/120 V = 1/3 A

5. Calculate the power dissipated in a toaster that has a resistance of 14 ohms plugged into a 120-V outlet.
$P = V^2/R = 120^2/14$ Ω = 1030 W

6. Calculate the yearly cost of running a 5-W electric clock continuously in a location where electricity costs 10 cents per kW·h.
Costs $4.38/year